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# Characterization of Solar Cells for Space Applications

## Volume II. Electrical Characteristics of Solarex 50-Micron Solar Cells as a Function of Intensity and Temperature

R. G. Downing  
T. F. Miyahira  
R. S. Weiss

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National Aeronautics and  
Space Administration

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California



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## ABSTRACT

Electrical characteristics of Solarex 50-micron-thick N/P silicon solar cells are presented in graphical and tabular format as a function of solar illumination intensity and temperature.

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## SECTION I

### INTRODUCTION

A series of reports is being generated to present parametric characterization data on both state-of-the-art and developmental solar cells of interest to the photovoltaic community. These data consist of the electrical characteristics of the candidate solar cell under a wide range of temperature and illumination intensity combinations of the type encountered in typical space applications. This series (JPL Publication 78-15) will consist of a number of reports, each report being devoted to a particular type of solar cell and identified by a volume number. Previously published reports with their associated solar cell descriptions are listed in a bibliography. Each report consists primarily of working graphs and tables and does not address itself to interpretive conclusions. The formatting of this series of reports will be relatively invariant to facilitate comparisons between the characteristics of any of the cell types considered in the series.

This report contains a set of parametric data on the Solarex 50-micron solar cell, which is a developmental cell. More recent solar cells of this type have been acquired and will be reported in a later volume. This set of data is presented to form a baseline for evaluating future progress in the development process of thin, high-efficiency solar cells.

## SECTION II

### CELL DESCRIPTION

The solar cells tested were manufactured by Solarex under JPL Contract No. 954290 entitled "Development of a Thin High Efficiency Silicon Solar Cell." These cells are currently in the developmental stage and are not at this time considered as an off-the-shelf commercial product, though efforts in this direction are in progress. The cells are fabricated from crucible-grown P-type silicon of a nominal resistivity of 2 ohm-cm. The cell dimensions are 2 x 2 x 0.005 cm (2 mils) thick. An antireflectance coating of tantalum pentoxide is applied to the top surface. An aluminum alloy p<sup>+</sup> back surface field (BSF) is diffused through the phosphorous layer remaining on the rear of the cell after junction formation. Since this procedure may not result in a complete BSF, we refer to it here as a compensated BSF. The electrical contacts consist of Ti-Pd-Ag with a chevron grid pattern on the top surface. No coverslips were applied for the characterization measurements.

## SECTION III

### TEST PROGRAM

The solar cells were mounted on a copper test plate using RTV 560. The test plate was in turn mounted to a heat sink with provisions for both heating and cooling so that the cells could be maintained at the desired temperature independent of the solar intensity. All testing was carried out in vacuum at a pressure of less than  $1 \times 10^{-6}$  torr.

The illumination source used was a Spectrolab Model X-25 Mark II Spectrosun filtered solar simulator. This simulator uses an optical integrator lens in the optical system which uniformly distributes a relatively collimated light beam at specific distances from a 2.5 KW short-arc xenon lamp. A system of filters mollifies the spectral distribution so that it approximates that of space sunlight. The light beam provides a pattern having a uniformity of  $\pm 1\%$  over an area of  $225 \text{ cm}^2$  at the test plane. Illumination intensity is varied by position of the simulator in combination with transmission filters. The solar simulator beam is introduced into the vacuum chamber through a window of 7940 fused silica. The solar intensity and spectral integrity of the solar simulator are constantly monitored and maintained using space calibrated standard cells obtained with the NASA/JPL solar cell balloon flight standardization program. Photographs of the solar cell, the assembled plate, and the experimental characterization test facility are shown in an appendix.

The temperature range covered in these measurements was  $-160$  to  $140^\circ \text{C}$ , while the solar intensity range covered was 5 to  $250 \text{ mW/cm}^2$ . The data were taken at each environment point in the matrix in the form of an I-V curve. The appropriate parameters were then read from the I-V curves and punched on cards for the computer analysis and curve plotting functions. The cell temperature was monitored by a thermocouple attached to the surface of a separate cell mounted with the cells under test. Prior, intermediate and post-test ambient measurements were performed daily to insure that the accuracy and stability of the test equipment and the test specimens themselves were maintained within  $\pm 2\%$  during the course of the testing program.

## SECTION IV

### DISCUSSION OF RESULTS

A computer program computes statistical averages and standard deviations with respect to the measured cells for each intensity-temperature measurement condition. It then produces summary tables, as shown in Tables 1 to 7, that display averages and standard deviations of the cell characteristics in a two-dimensional array format, one dimension representing cell temperature and the second dimension representing incoming light intensity (AMO spectrum). The program then produces plots of the various electrical parameters of interest, with

either incident intensity or cell temperature as the independent variable, as shown in Figure 1 to 14. Least square fits to the data points are then made automatically to the measured data points using a second-degree polynomial for most parameters. The  $V_{oc}$  and  $V_{mp}$  data points are fit with a linear equation. The curve factors and AMO efficiencies are not fit but interconnected from point to point. In addition, the program calculates the temperature coefficients of the pertinent cell electrical parameters of interest, using the aforementioned curve fits, and plots these as a function of temperature, with intensity as a parameter, as shown in Figures 15 to 18.

The figures are intended to be working artifacts; that is, they are formatted in such a way that they can supply information of a general nature or may be used to generate predictions, comparisons, computer input data, etc. To facilitate comparisons and inputting, all units are standardized as follows:

- (1) All currents are in units of  $\text{mA}/\text{cm}^2$ .
- (2) All voltages are in units of  $\text{mV}$ .
- (3) All power outputs are in units of  $\text{mW}/\text{cm}^2$ .
- (4) All curve factors are in dimensionless units.
- (5) All efficiencies are in percentages and are based on total cell area.
- (6) All temperatures are in  $^{\circ}\text{C}$ .
- (7) All incoming intensities are in units of  $\text{mW}/\text{cm}^2$  and are representative of an AMO spectrum.
- (8) All geometric dimensions are in units of  $\text{cm}$  or  $\mu\text{m}$  (whichever is most convenient conceptually).

The tables included in this report contain complete numerical information with respect to the average values of the following solar cell electrical parameters:  $I_{sc}$ ,  $V_{oc}$ ,  $IP_{max}$ ,  $VP_{max}$ , CF, and efficiency at each intensity-temperature combination. For each such parameter at each such intensity-temperature combination, the standard deviation is presented to provide estimates of statistical validity. All current and power output data are on the basis of unit area derived by dividing measured output by total cell area. All solar cell efficiency numerical data are based on total cell area.

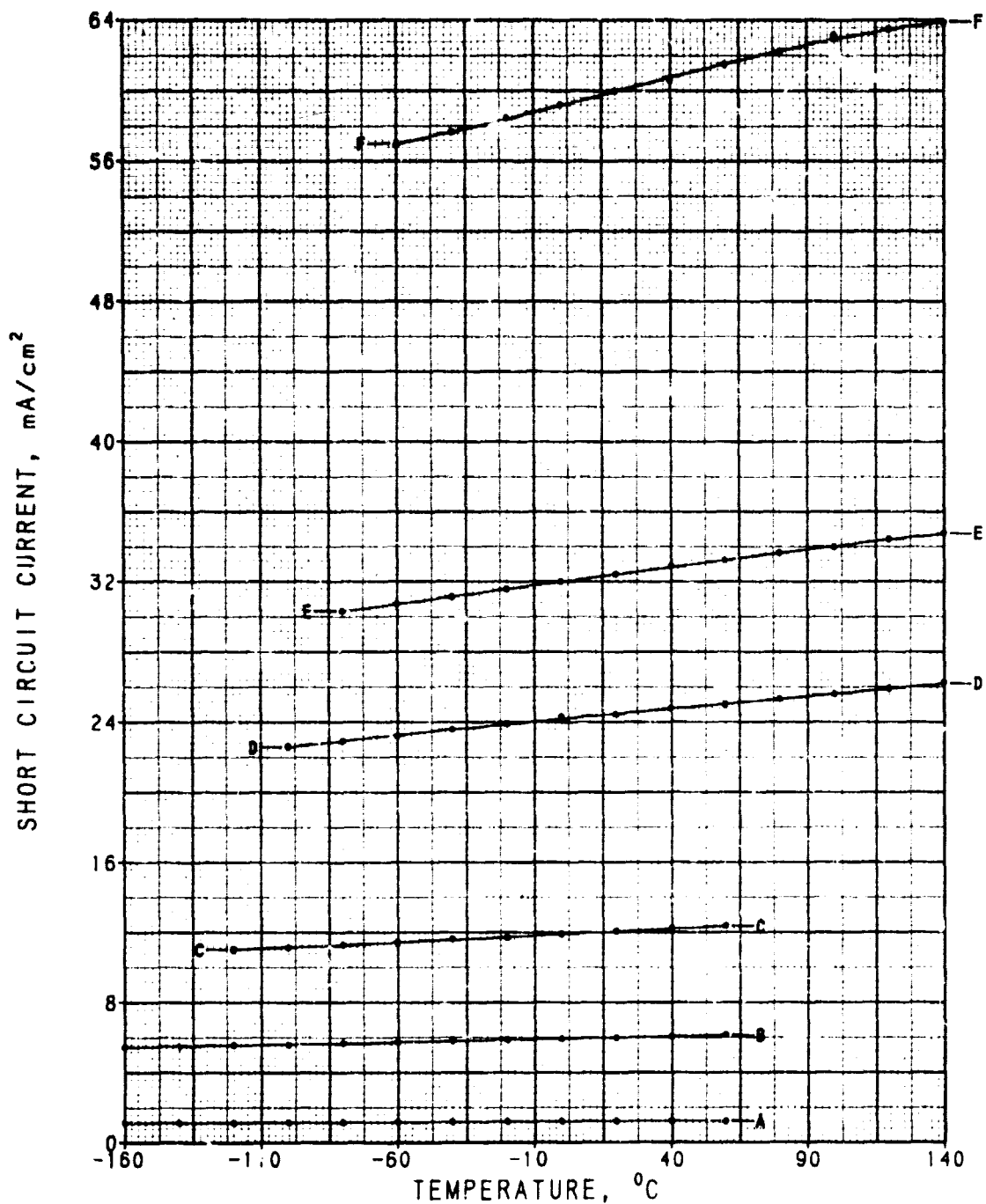
In this report we have presented data on a relatively new type of cell which is in the development cycle. Later cells of this type which are now in-house exhibit even superior electrical performance and will be characterized in the near future. The importance of the data contained in this report lies in the establishment of a baseline for future evaluation of the thin, high-efficiency solar cell.

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Characterization of Solar Cells for Space Applications, JPL Publication  
78-15

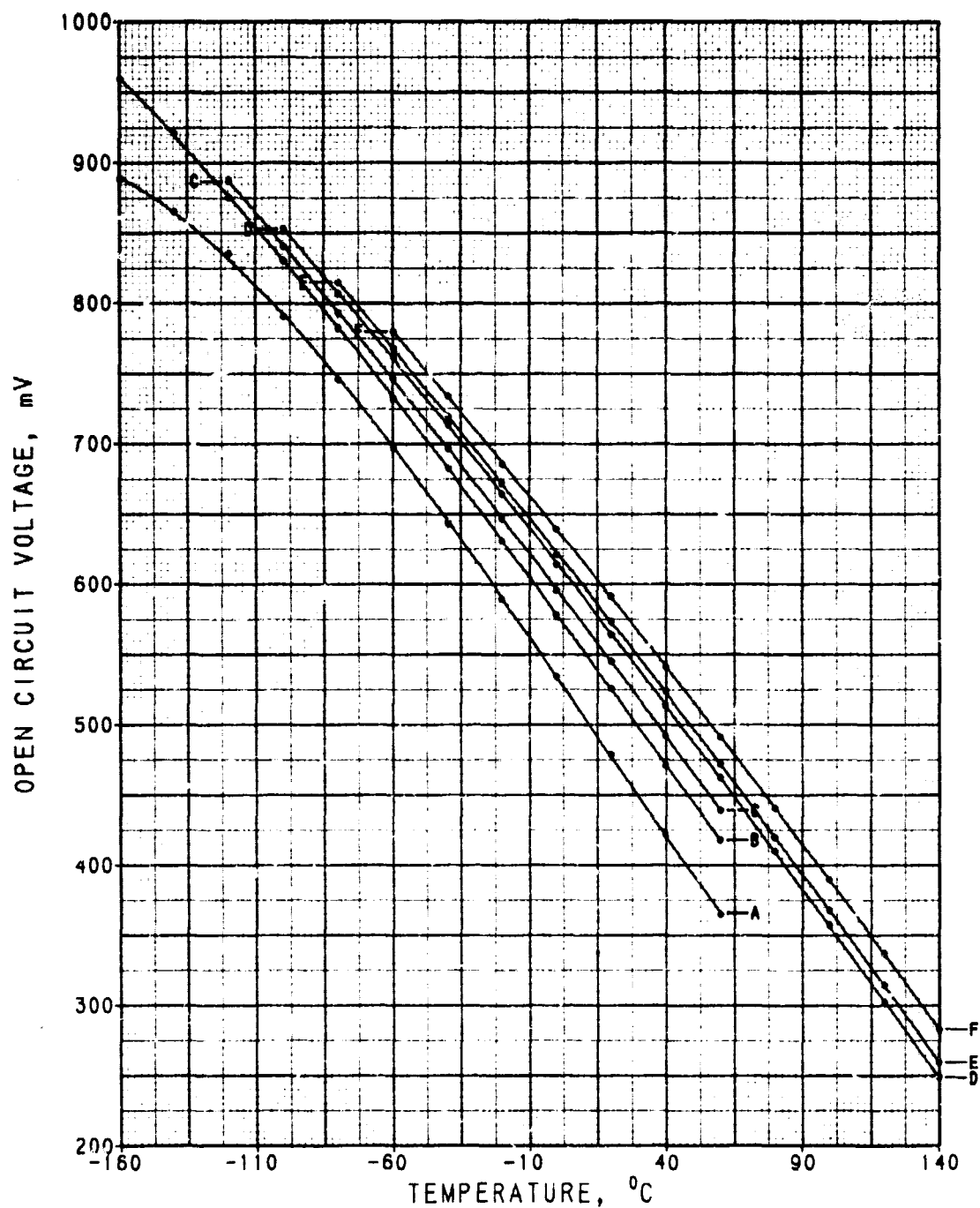
Volume 1. Electrical Characteristics of OCLI Violet Solar Cells  
as a Function of Intensity and Temperature, March 15, 1978



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
N/P 2 OHM-CM CG SILICON  
2 X 2 X .005 CM  
TI-PD-AG CONTACTS  
TA205 A-R COATING  
NO COVERSLIDE  
SAMPLE SIZE 10

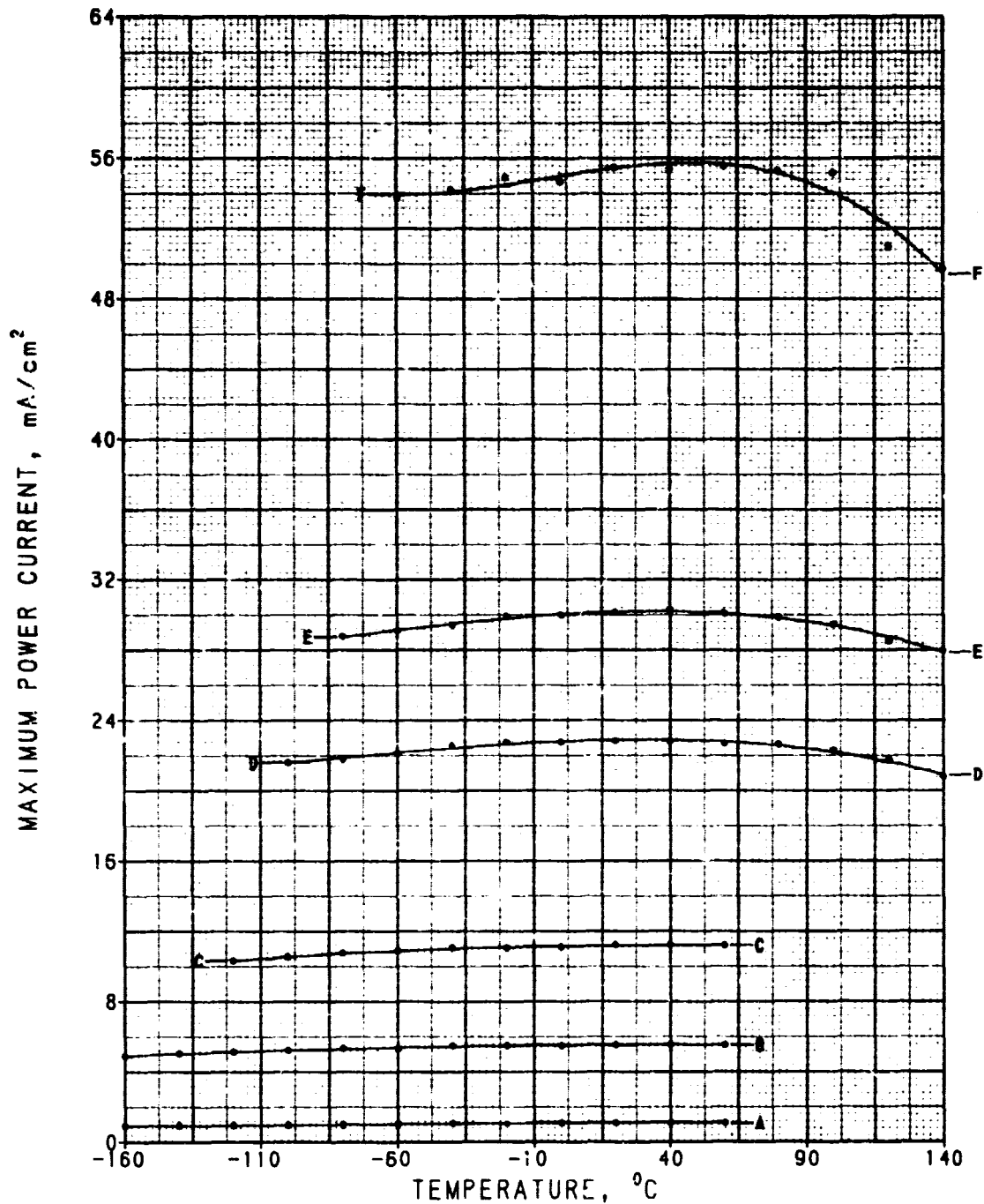
Figure 1. Average  $I_{sc}/cm^2$  as a Function of Temperature



ID	$mW/cm^2$
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAR EX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 2. Average  $V_{OC}$  as a Function of Temperature



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 3. Average  $I_{mp}/cm^2$  as a Function of Temperature

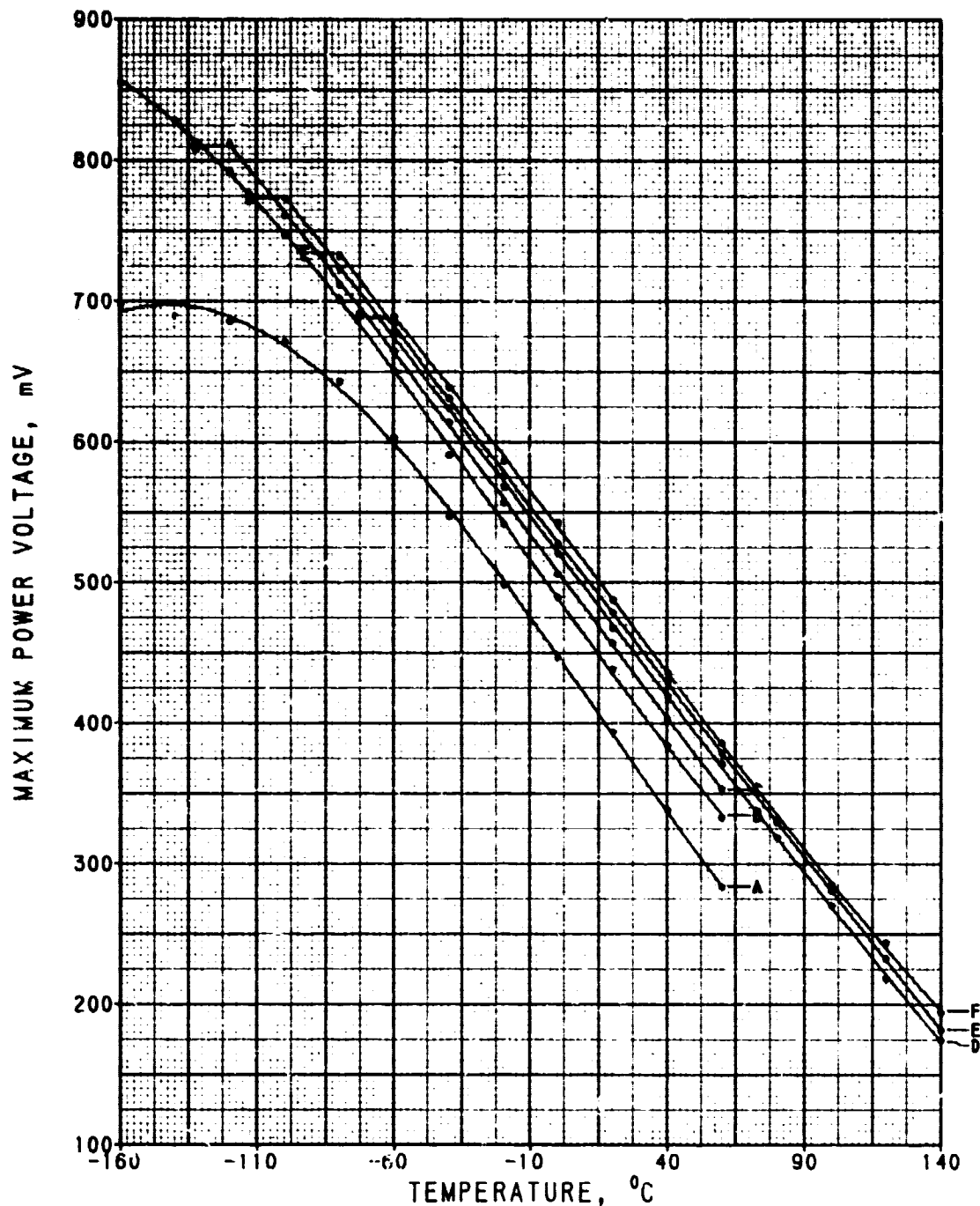
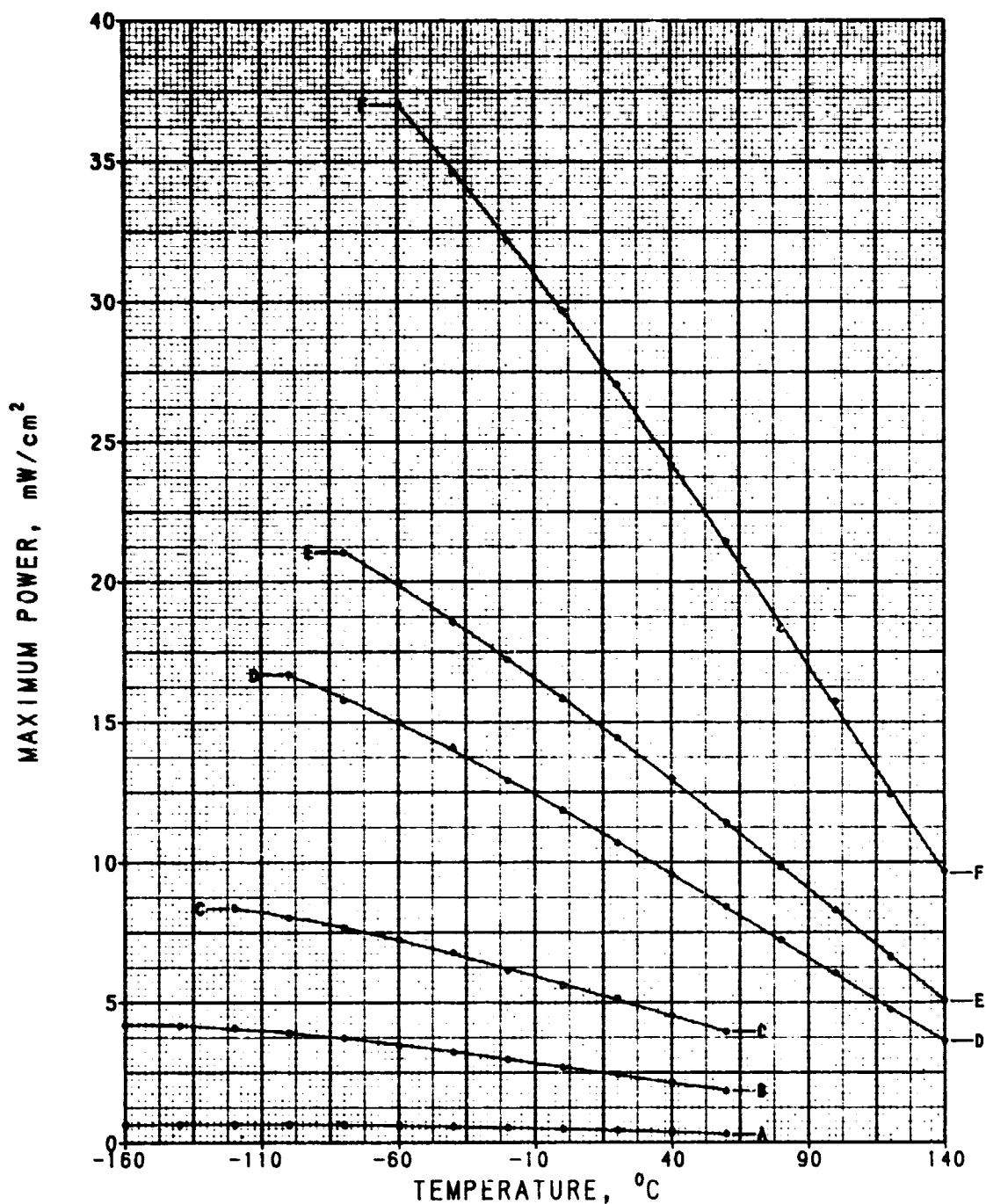


Figure 4. Average  $V_{mp}$  as a Function of Temperature

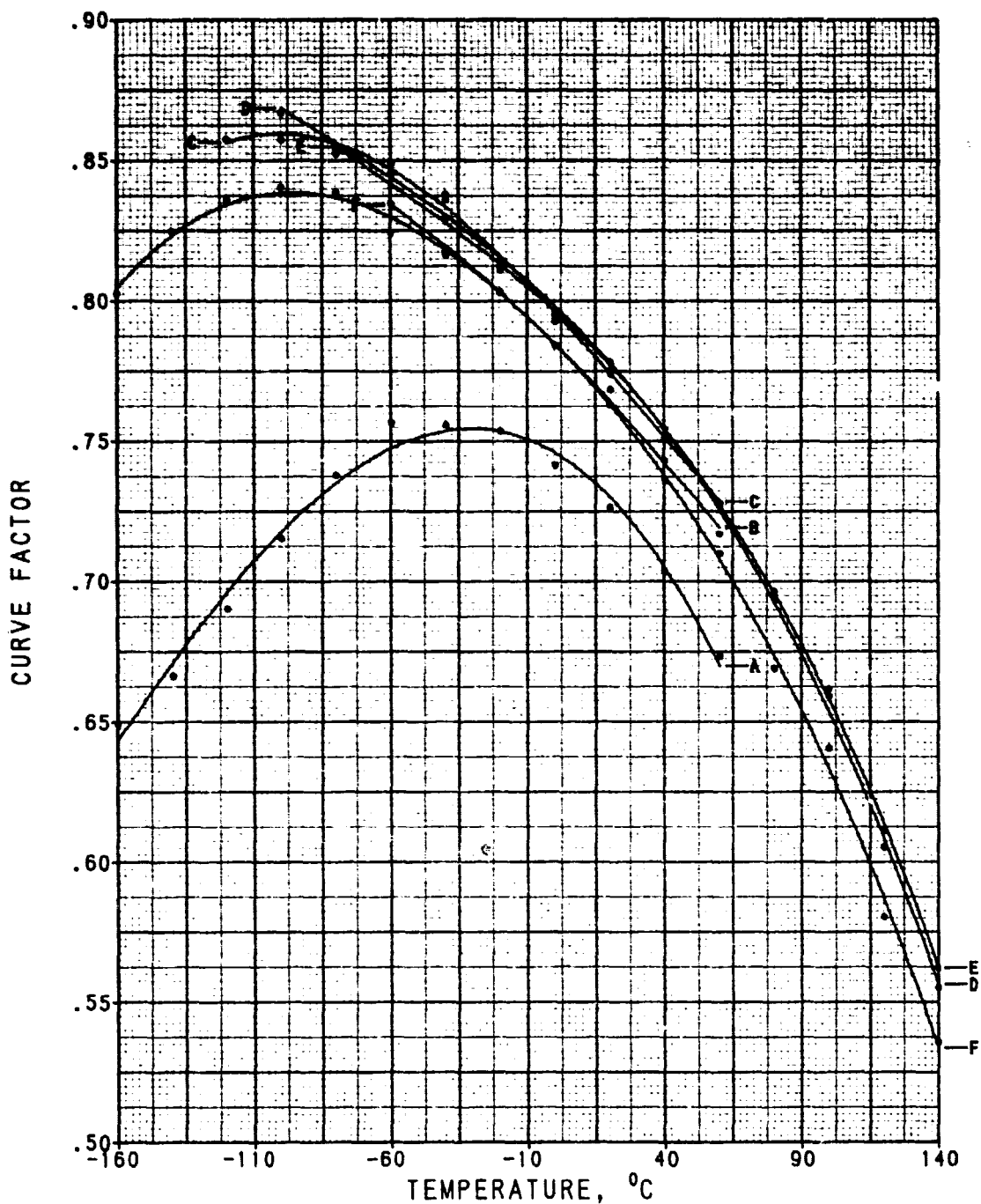




ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

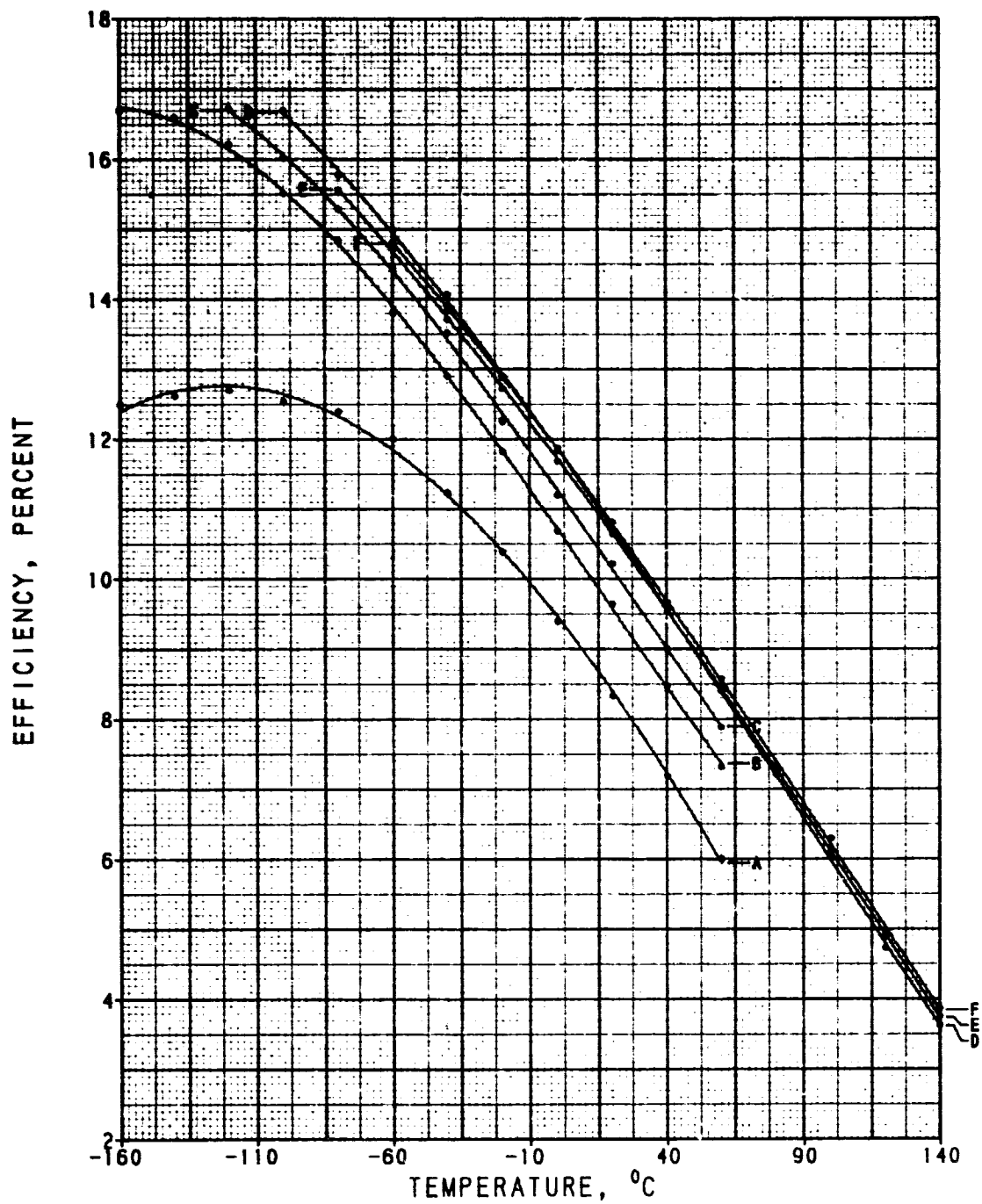
Figure 5. Average  $P_{max}/cm^2$  as a Function of Temperature



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TAZ05 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

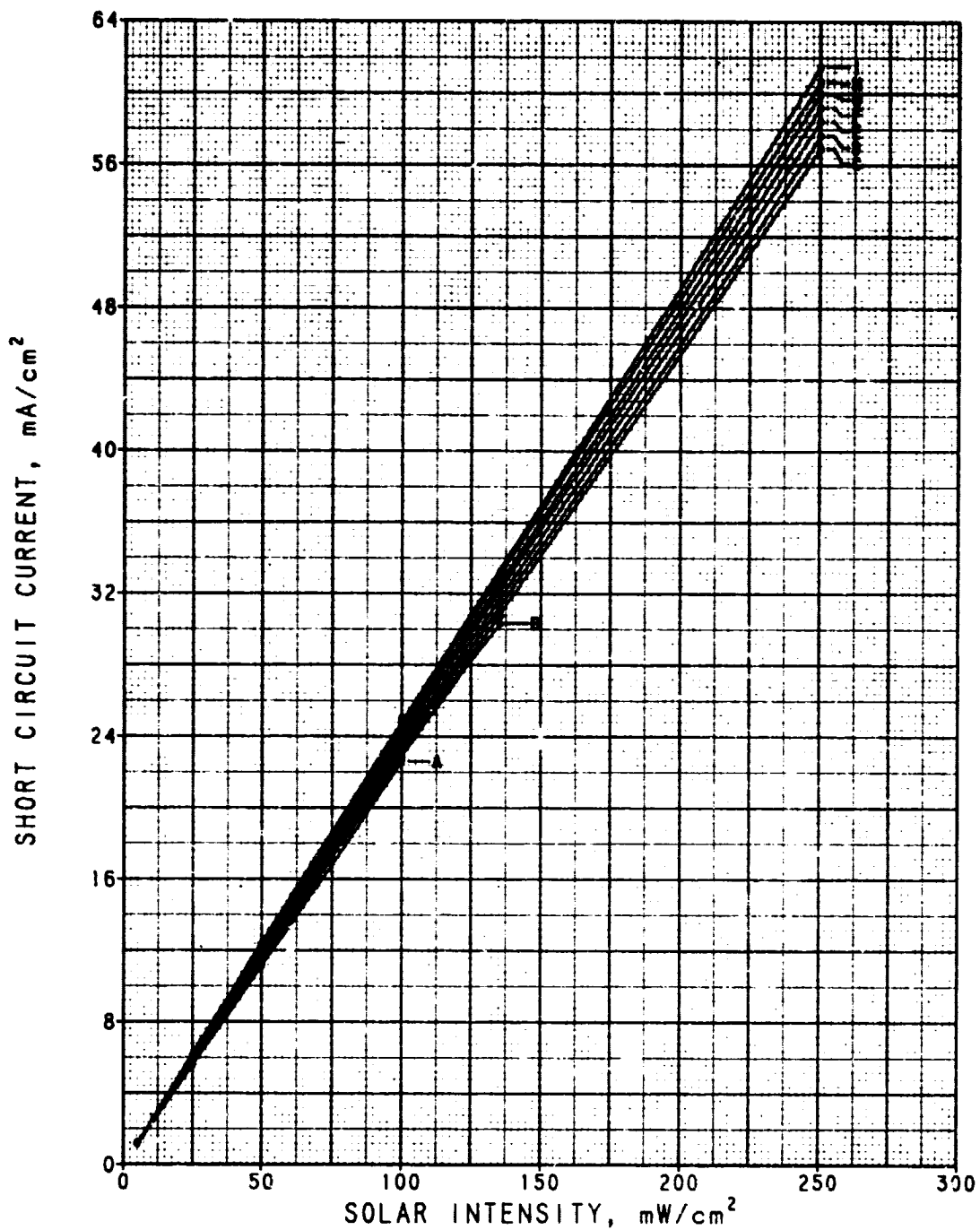
Figure 6. Average Curve Factor as a Function of Temperature



ID mW/cm²  
A 5.0  
B 25.0  
C 50.0  
D 100.0  
E 135.3  
F 250.0

SOLAREX COMPENSATED BSF  
N/P 2 OHM-CM CG SILICON  
2 X 2 X .005 CM  
TI-PD-AG CONTACTS  
TA205 A-R COATING  
NO COVERSLIDE  
SAMPLE SIZE 10

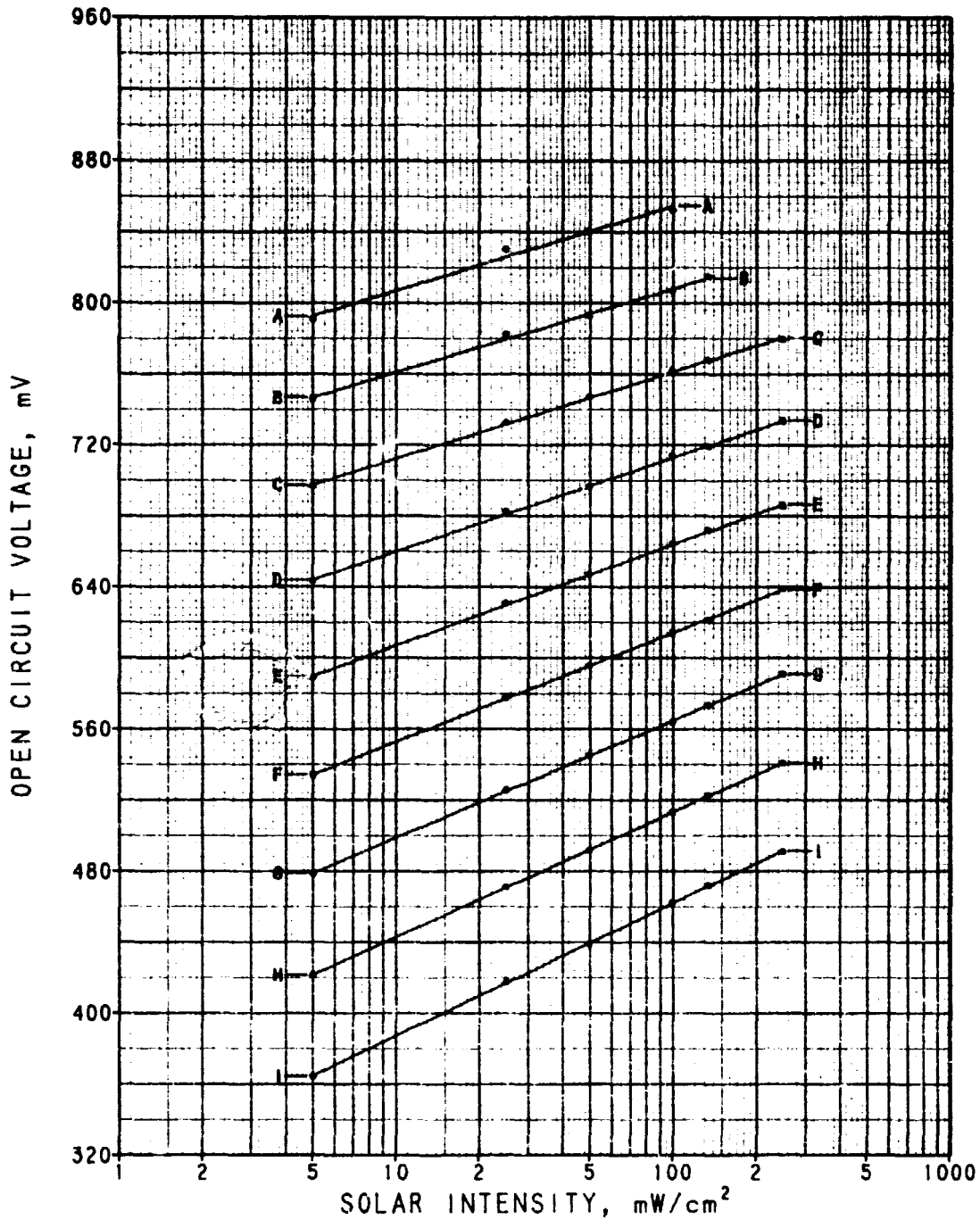
Figure 7. Average AMO Efficiency as a Function of Temperature



ID	°C	ID	°C
A	-100.0	I	60.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
 N/P 2 CHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TAZOS A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

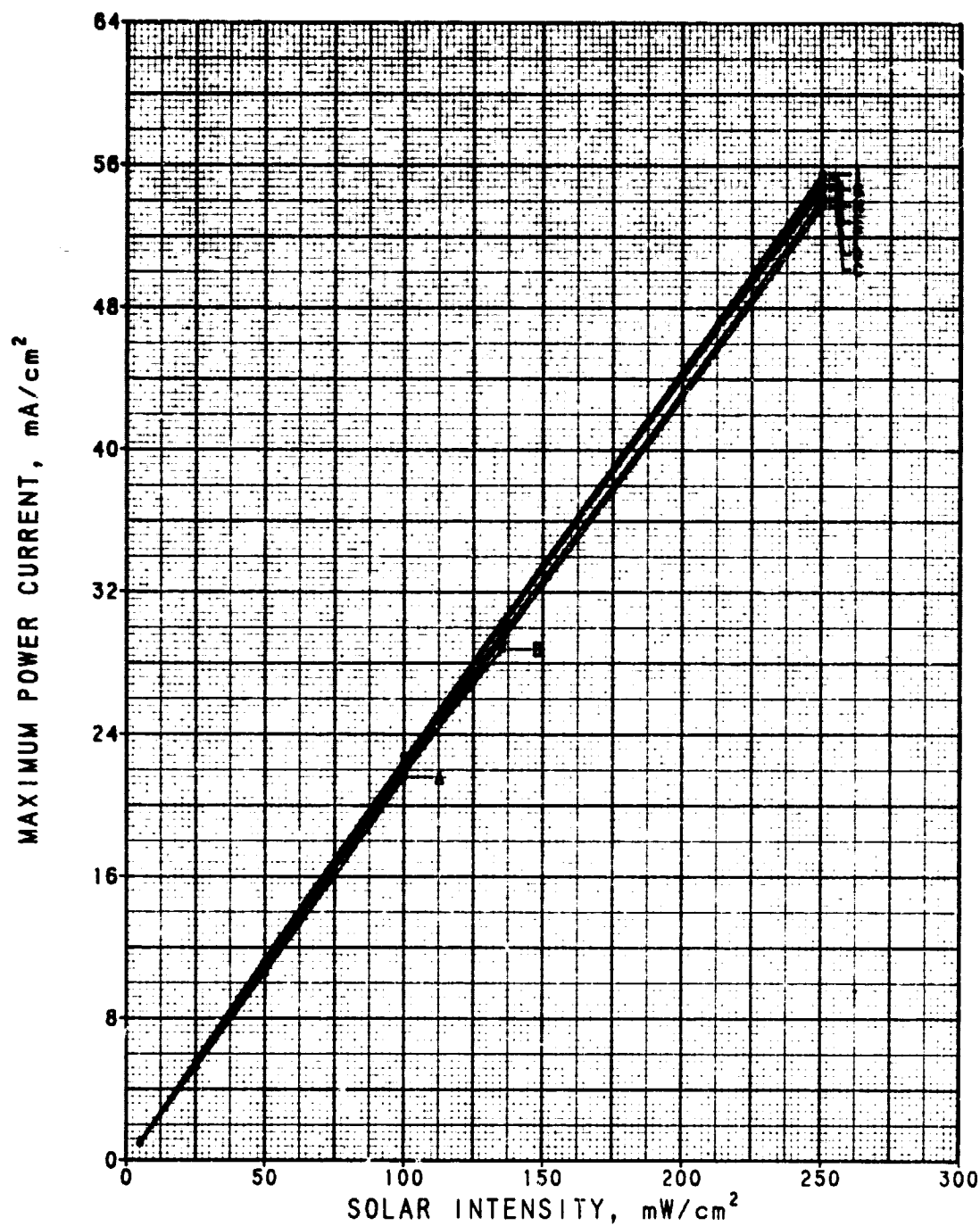
Figure 8. Average  $I_{sc}/cm^2$  as a Function of Intensity



ID	°C	ID	°C
A	-100.0	I	80.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
N/P 2 OHM-CM CG SILICON  
2 X 2 X .005 CM  
TI-PD-AG CONTACTS  
TA205 A-R COATING  
NO COVERSLIDE  
SAMPLE SIZE 10

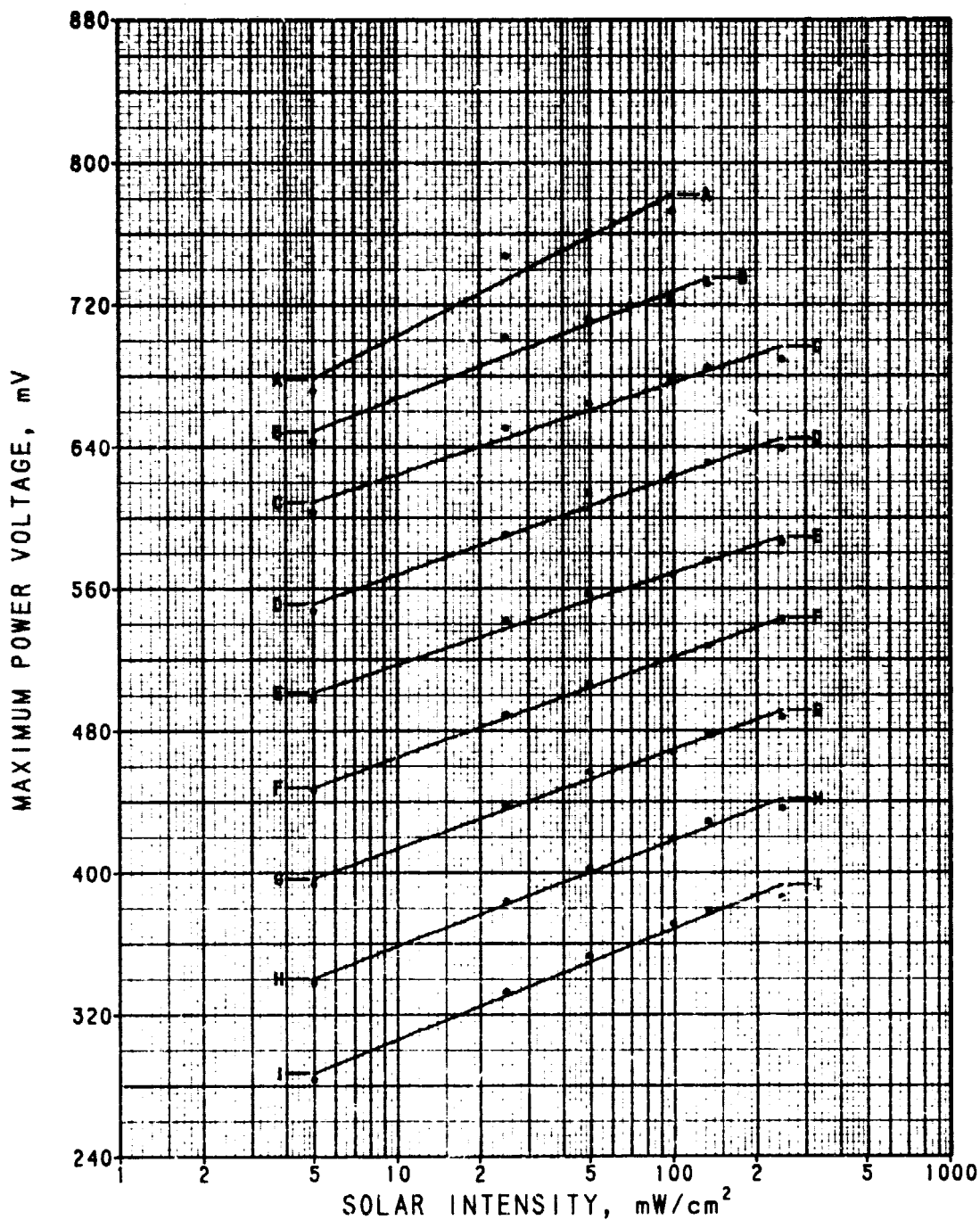
Figure 9. Average  $V_{OC}$  as a Function of Intensity



ID	°C	ID	°C
A	-100.0	I	60.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

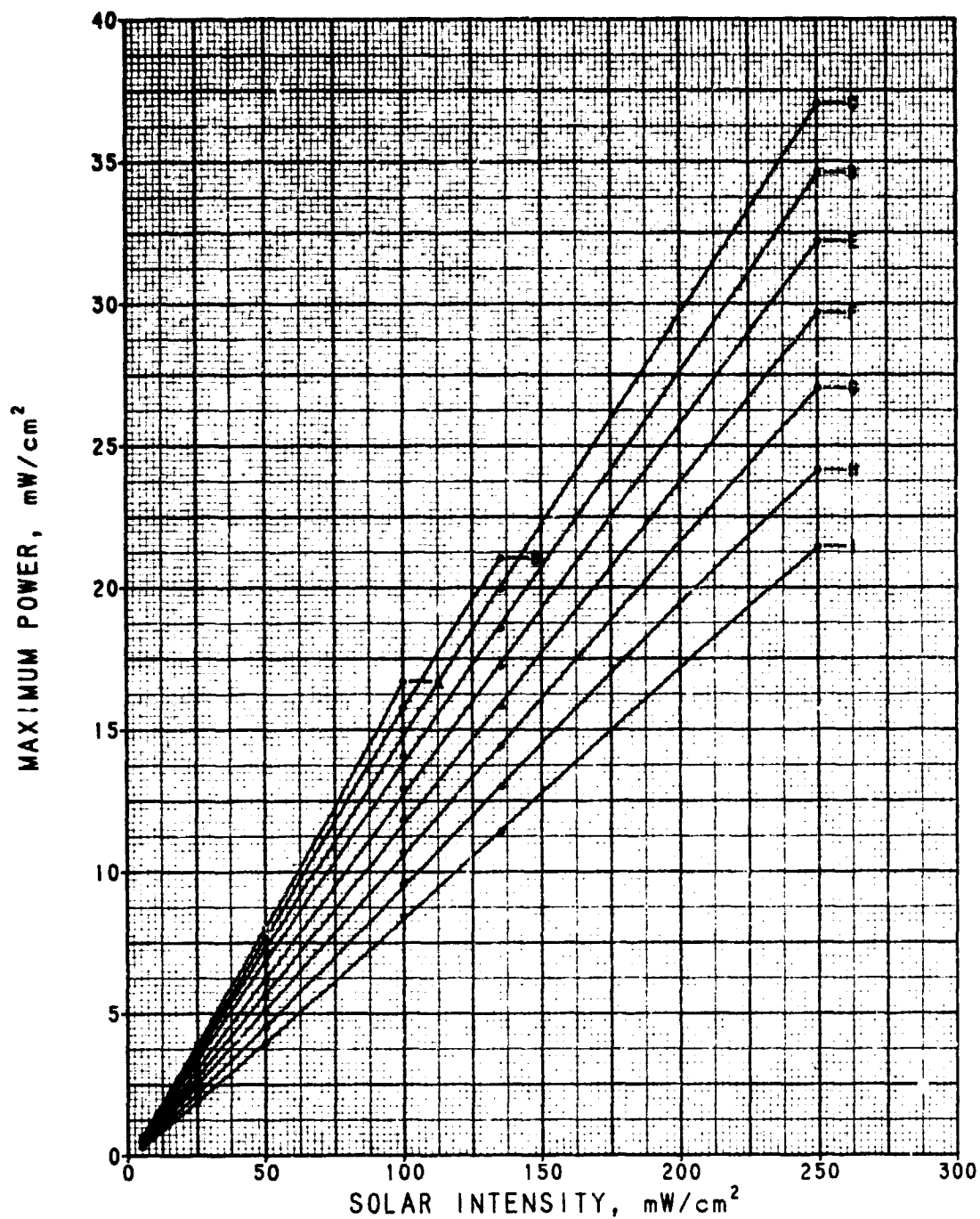
Figure 10. Average  $I_{mp}/\text{cm}^2$  as a Function of Intensity



ID	$^{\circ}\text{C}$	ID	$^{\circ}\text{C}$
A	-100.0	I	60.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 11. Average  $V_{mp}$  as a Function of Intensity



ID	$^{\circ}\text{C}$	ID	$^{\circ}\text{C}$
A	-100.0	I	80.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 12. Average  $P_{\text{max}}/\text{cm}^2$  as a Function of Intensity



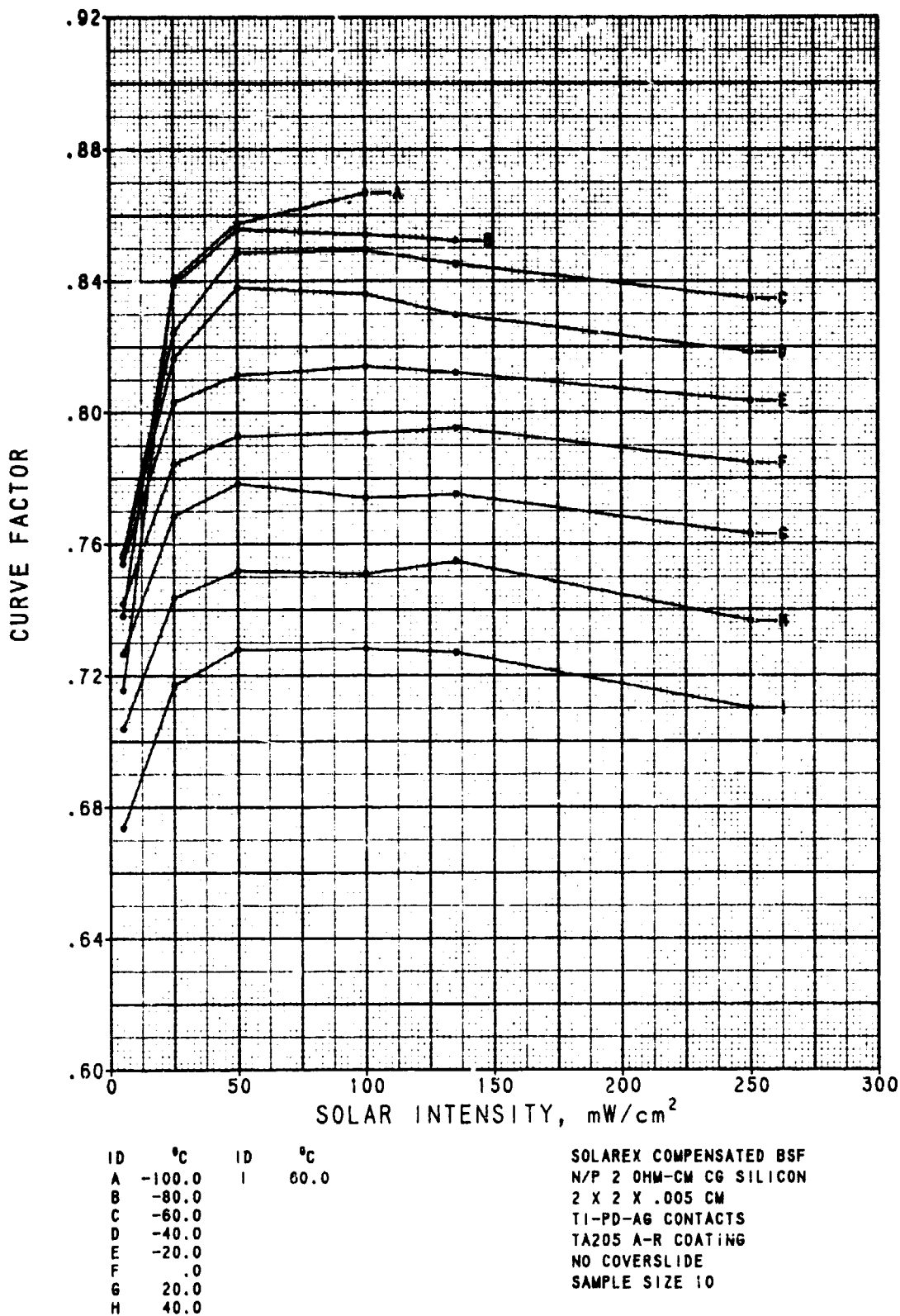
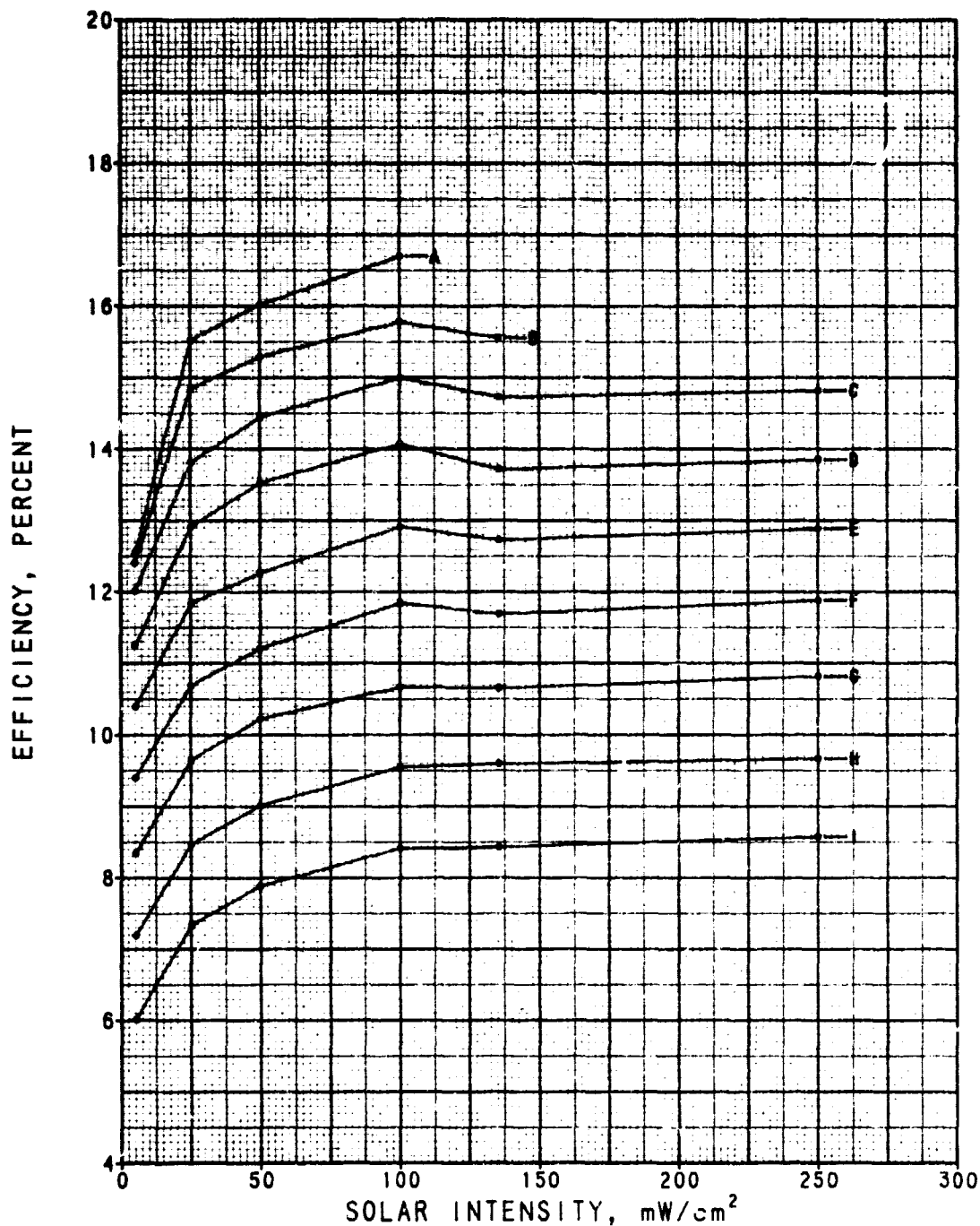


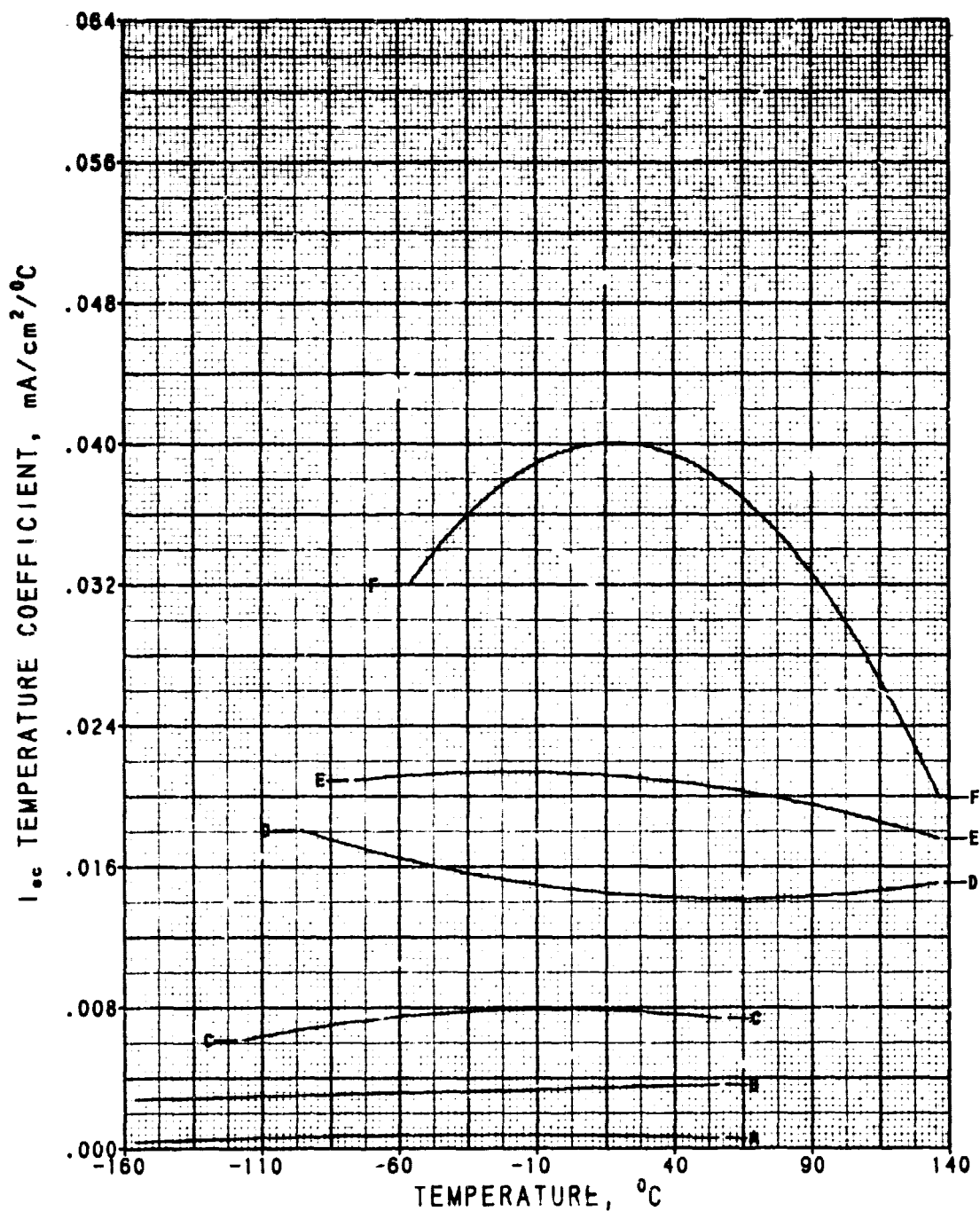
Figure 13. Average Curve Factor as a Function of Intensity



ID	°C	ID	°C
A	-100.0	I	60.0
B	-80.0		
C	-60.0		
D	-40.0		
E	-20.0		
F	0.0		
G	20.0		
H	40.0		

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

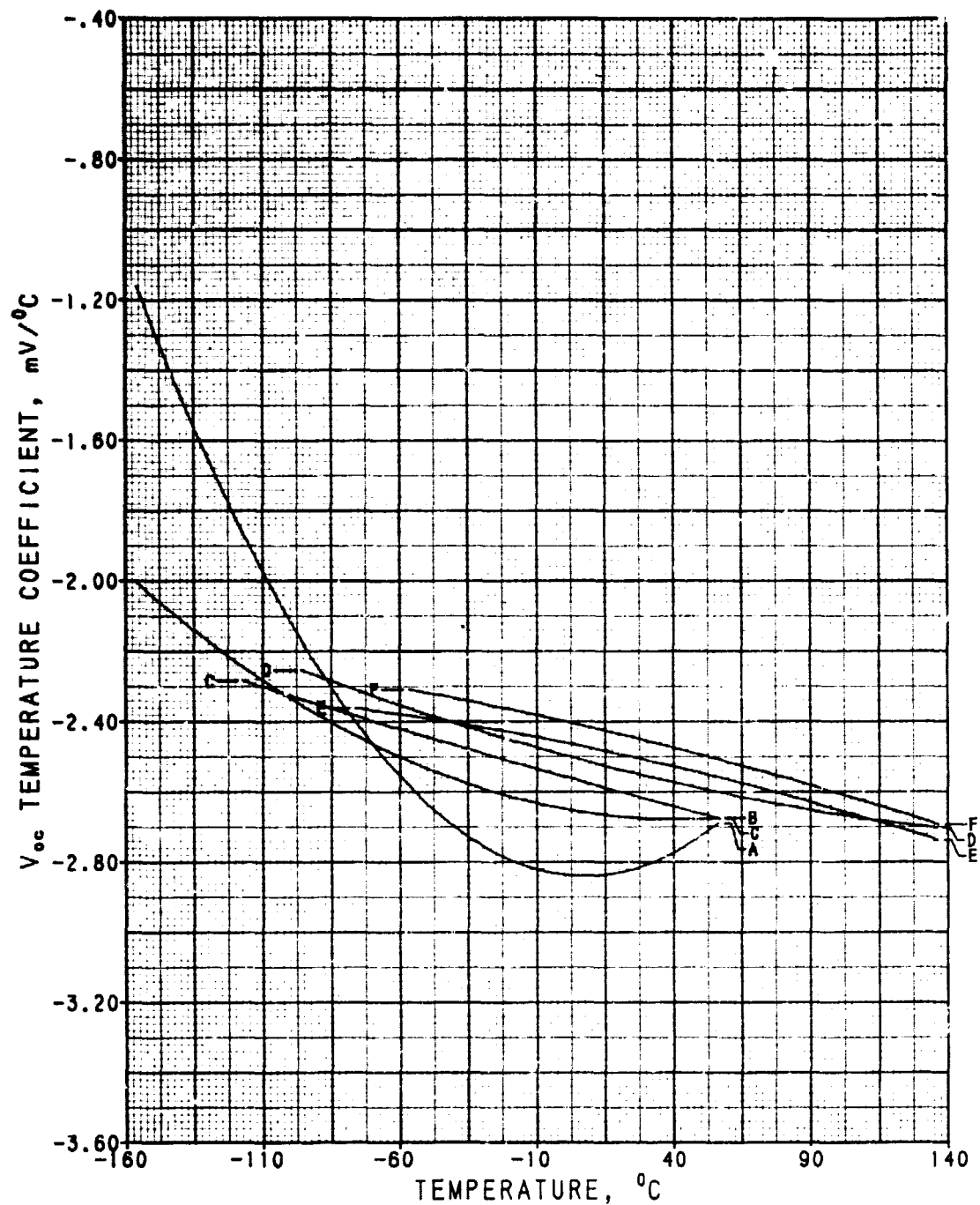
Figure 14. Average AMO Efficiency as a Function of Intensity



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

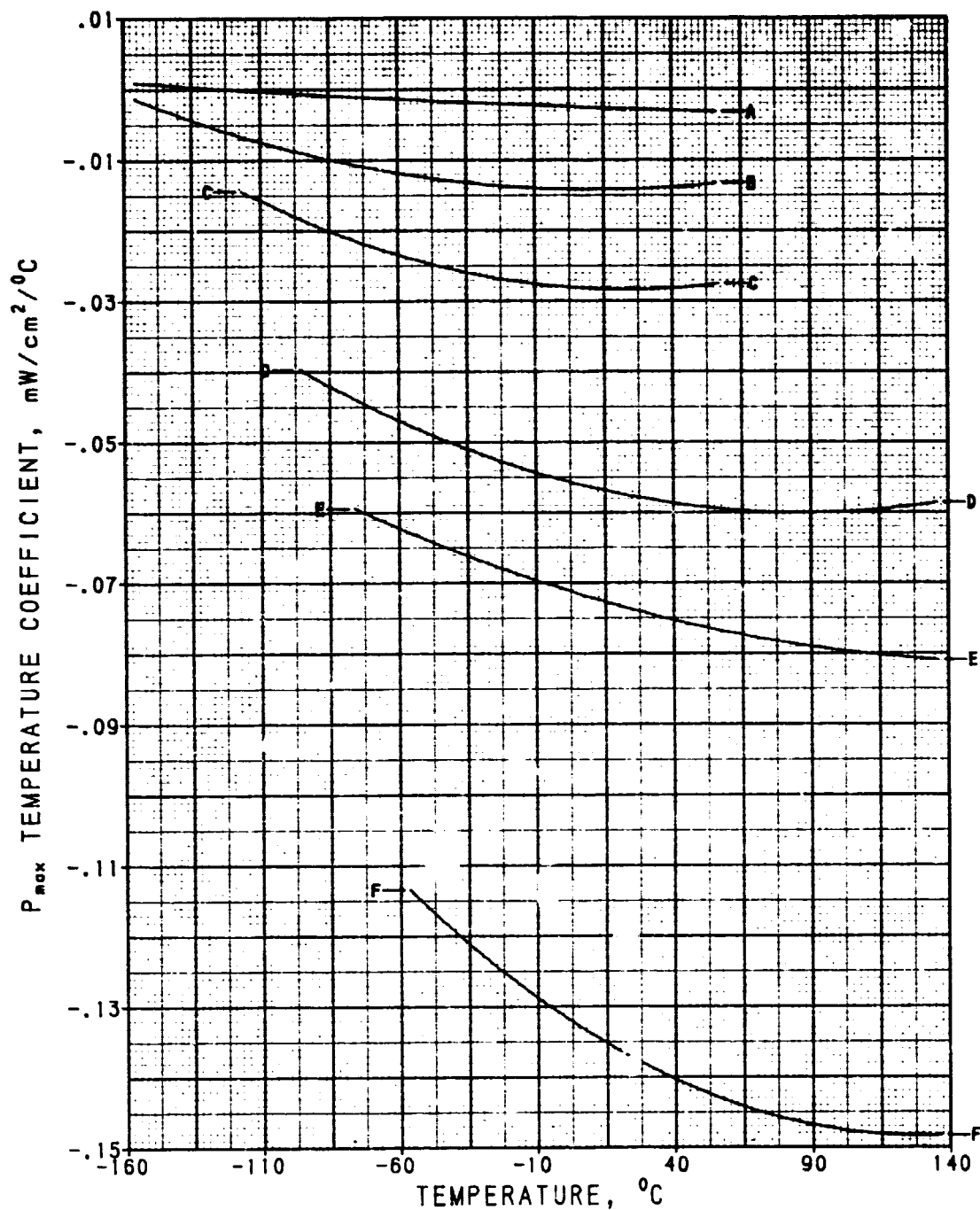
Figure 15.  $I_{sc}$  Temperature Coefficient



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 1C

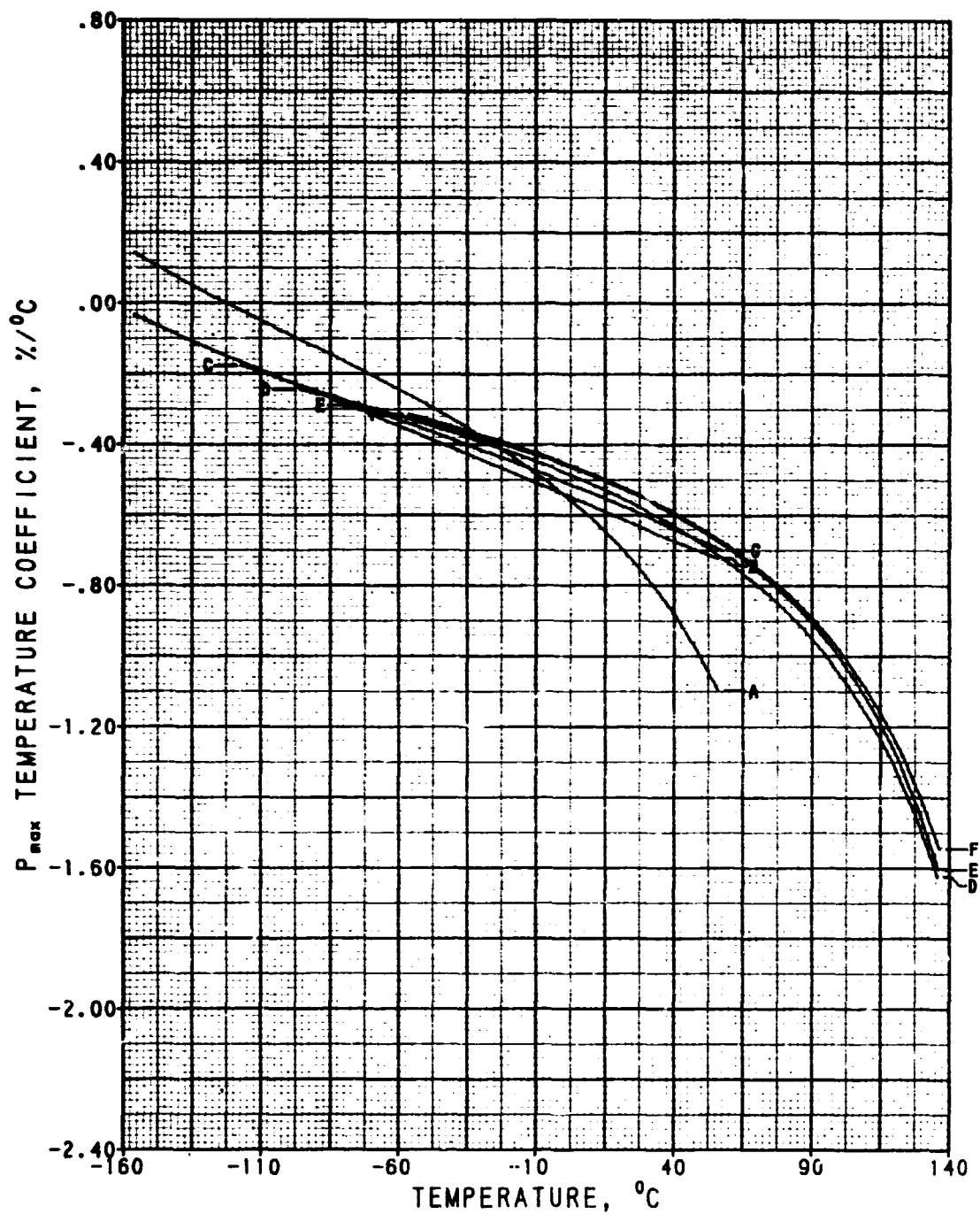
Figure 16.  $V_{oc}$  Temperature Coefficient



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 17. Absolute  $P_{max}$  Temperature Coefficient



ID	mW/cm <sup>2</sup>
A	5.0
B	25.0
C	50.0
D	100.0
E	135.3
F	250.0

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM C6 SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

Figure 18. Percent  $P_{max}$  Temperature Coefficient

Table 1. Average Short Circuit Current

SOLARFX COMPENSATED RSF  
 N/P 2 OHM-CM C6 SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	135.30	250.00
-160.00	1.08 (.04)	5.42 (.20)	-	-	-	-
-140.00	1.09 (.04)	5.46 (.19)	-	-	-	-
-120.00	1.10 (.05)	5.54 (.22)	10.99 (.40)	-	-	-
-100.00	1.11 (.04)	5.56 (.20)	11.12 (.43)	22.60 (.77)	-	-
-80.00	1.13 (.05)	5.65 (.21)	11.27 (.44)	22.89 (.77)	30.31 (1.20)	-
-60.00	1.14 (.05)	5.71 (.22)	11.39 (.42)	23.17 (.78)	30.72 (1.23)	56.94 (2.47)
-40.00	1.16 (.05)	5.79 (.23)	11.59 (.42)	23.58 (.78)	31.11 (1.21)	57.65 (2.62)
-20.00	1.17 (.05)	5.84 (.21)	11.68 (.44)	23.88 (.79)	31.55 (1.24)	58.45 (2.58)
.00	1.19 (.04)	5.89 (.22)	11.87 (.42)	24.29 (.78)	32.01 (1.22)	59.20 (2.63)
20.00	1.20 (.04)	5.96 (.22)	12.05 (.45)	24.44 (.85)	32.43 (1.24)	59.97 (2.61)
40.00	1.21 (.05)	6.04 (.21)	12.18 (.48)	24.78 (.80)	32.90 (1.22)	60.62 (2.63)
60.00	1.22 (.04)	6.12 (.21)	12.33 (.45)	24.99 (.79)	33.23 (1.27)	61.48 (2.75)
80.00	-	-	-	25.32 (.82)	33.65 (1.27)	62.15 (2.56)
100.00	-	-	-	25.61 (.83)	33.99 (1.24)	63.13 (2.65)
120.00	-	-	-	25.91 (.84)	34.43 (1.31)	63.47 (2.58)
140.00	-	-	-	26.21 (.80)	34.79 (1.30)	63.83 (2.55)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 2. Average Open Circuit Voltage

SOLAREX COMPENSATED BSF  
N/P 2 OHM-CM CG SILICON  
2 X 2 X .005 CM  
TI-PD-AG CONTACTS  
TA205 A-R COATING  
NO COVERSLIDE  
SAMPLE SIZE 10

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	135.30	250.00
-160.00	888.09 (37.48)	959.14 (2.83)	-	-	-	-
-140.00	864.89 (22.77)	920.87 (1.97)	-	-	-	-
-120.00	834.98 (12.71)	875.11 (2.41)	886.85 (2.08)	-	-	-
-100.00	790.51 (7.65)	830.23 (2.74)	840.11 (2.66)	852.18 (2.55)	-	-
-80.00	745.78 (4.73)	782.27 (3.08)	792.76 (3.25)	806.68 (2.76)	814.74 (2.84)	-
-60.00	696.85 (4.35)	732.55 (2.84)	746.75 (2.98)	761.70 (2.66)	767.73 (2.96)	779.69 (4.32)
-40.00	643.27 (4.55)	682.57 (2.95)	696.40 (3.22)	713.56 (2.96)	719.10 (3.55)	733.70 (3.46)
-20.00	589.01 (4.19)	630.70 (3.31)	646.86 (3.18)	664.30 (2.97)	672.22 (4.36)	685.70 (4.36)
.00	534.22 (3.91)	577.87 (3.31)	595.46 (3.43)	613.96 (3.56)	621.24 (3.43)	639.12 (3.71)
20.00	478.61 (4.01)	525.68 (3.49)	545.18 (3.41)	563.86 (3.48)	573.41 (3.61)	591.08 (3.95)
40.00	421.54 (3.73)	471.04 (4.42)	491.69 (3.85)	513.25 (3.71)	522.66 (3.77)	540.88 (4.09)
60.00	364.38 (3.89)	417.61 (4.19)	439.00 (4.05)	462.09 (3.73)	471.98 (3.98)	490.98 (4.24)
80.00	-	-	-	409.77 (3.69)	419.34 (4.03)	440.44 (4.41)
100.00	-	-	-	356.68 (4.24)	367.43 (4.74)	389.14 (4.49)
120.00	-	-	-	301.89 (3.73)	314.25 (4.41)	336.95 (4.94)
140.00	-	-	-	248.63 (3.99)	259.22 (4.71)	282.53 (5.67)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.



Table 3. Average Maximum Power Current

SOLAREX COMPENSATED RSF  
N/P 2 OHM-CM C6 SILICON  
2 X 2 X .005 CM  
TI-PD-AG CONTACTS  
TA205 A-R COATING  
NO COVERSLIDE  
SAMPLE SIZE 10

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	145.30	252.00
-160.00	.89 (.06)	4.88 (.24)	-	-	-	-
-140.00	.91 (.07)	5.01 (.25)	-	-	-	-
-120.00	.92 (.07)	5.12 (.23)	10.30 (.35)	-	-	-
-100.00	.93 (.07)	5.19 (.24)	10.52 (.40)	21.60 (.68)	-	-
-80.00	.96 (.07)	5.29 (.23)	10.73 (.43)	21.81 (.73)	28.75 (1.05)	-
-60.00	1.00 (.06)	5.30 (.25)	10.86 (.39)	22.12 (.71)	29.10 (1.05)	53.75 (2.02)
-40.00	1.03 (.05)	5.46 (.23)	11.01 (.40)	22.53 (.74)	29.41 (1.13)	54.17 (2.41)
-20.00	1.04 (.05)	5.46 (.24)	11.01 (.42)	22.73 (.75)	29.90 (1.12)	54.92 (2.43)
.00	1.05 (.05)	5.46 (.23)	11.07 (.43)	22.74 (.75)	29.97 (1.12)	54.67 (2.23)
20.00	1.06 (.04)	5.50 (.24)	11.19 (.41)	22.81 (.82)	30.11 (1.15)	55.45 (2.32)
40.00	1.06 (.04)	5.51 (.22)	11.19 (.48)	22.78 (.68)	30.24 (1.13)	55.35 (2.29)
60.00	1.06 (.04)	5.50 (.19)	11.15 (.44)	22.66 (.77)	30.10 (1.16)	55.55 (2.32)
80.00	-	-	-	22.62 (.71)	29.84 (1.17)	55.25 (2.00)
100.00	-	-	-	22.27 (.78)	29.45 (1.19)	55.15 (2.14)
120.00	-	-	-	21.71 (.69)	28.49 (.98)	50.95 (1.99)
140.00	-	-	-	20.76 (.68)	27.95 (1.10)	49.72 (1.92)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 4. Average Maximum Power Voltage

SOLAREX COMPENSATED RSF N/P 2 OHM-CM C6 SILICON 2 X 2 X .005 CM TI-PD-AG CONTACTS TA205 A-R COATING NO COVERSLIDE SAMPLE SIZE 10						
CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM <sup>2</sup> )*2)					
	5.00	25.00	50.00	100.00	135.30	250.00
-160.00	697.90 (67.18)	855.20 (22.14)	-	-	-	-
-140.00	689.40 (56.93)	828.30 (11.77)	-	-	-	-
-120.00	685.60 (47.90)	791.90 (9.71)	811.50 (6.70)	-	-	-
-100.00	671.50 (34.44)	747.50 (5.62)	761.00 (3.46)	772.70 (4.85)	-	-
-80.00	643.20 (20.31)	701.70 (5.27)	712.00 (5.08)	723.10 (4.86)	742.10 (7.31)	-
-60.00	603.20 (11.89)	650.70 (6.13)	664.60 (5.13)	677.70 (2.36)	684.70 (6.00)	689.20 (7.35)
-40.00	547.30 (11.34)	590.70 (5.96)	614.20 (3.55)	624.20 (4.42)	650.90 (4.01)	639.00 (3.23)
-20.00	497.90 (8.48)	541.90 (4.15)	556.70 (4.72)	568.00 (2.58)	575.90 (4.77)	586.40 (8.24)
.00	446.50 (7.91)	489.40 (4.30)	506.10 (4.01)	520.60 (4.79)	527.60 (4.53)	542.90 (5.22)
20.00	393.80 (7.36)	438.40 (2.37)	456.70 (3.77)	467.70 (2.54)	478.70 (6.83)	487.70 (3.95)
40.00	338.00 (5.87)	383.90 (5.00)	402.40 (3.31)	419.20 (3.01)	429.10 (4.07)	436.30 (6.31)
60.00	283.30 (5.48)	333.00 (4.22)	353.20 (5.01)	371.10 (2.96)	378.80 (4.94)	385.80 (4.76)
80.00	-	-	-	318.50 (3.41)	329.20 (2.39)	331.40 (10.57)
100.00	-	-	-	270.30 (4.32)	280.70 (4.00)	285.30 (4.14)
120.00	-	-	-	218.10 (3.75)	232.20 (5.37)	243.60 (5.76)
140.00	-	-	-	174.20 (2.94)	181.40 (5.82)	194.20 (5.29)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 5. Average Maximum Power

SOLAREX COMPENSATED BSF N/P 2 OHM-CM CG SILICON 2 X 2 X .005 CM TI-PD-AG CONTACTS TA205 A-R COATING NO COVERSLIDE SAMPLE SIZE 10						
CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	145.30	250.00
-160.00	.62 (.09)	4.17 (.27)	-	-	-	-
-140.00	.63 (.09)	4.15 (.24)	-	-	-	-
-120.00	.64 (.08)	4.05 (.20)	8.36 (.32)	-	-	-
-100.00	.63 (.07)	3.88 (.20)	8.01 (.31)	16.69 (.57)	-	-
-80.00	.62 (.05)	3.71 (.17)	7.64 (.32)	15.77 (.56)	21.05 (.84)	-
-60.00	.60 (.04)	3.45 (.17)	7.22 (.27)	14.99 (.51)	19.93 (.78)	37.05 (1.55)
-40.00	.56 (.03)	3.23 (.14)	6.76 (.26)	14.07 (.52)	18.56 (.72)	34.62 (1.51)
-20.00	.52 (.03)	2.96 (.13)	6.13 (.27)	12.91 (.43)	17.22 (.69)	32.20 (1.42)
.00	.47 (.02)	2.67 (.13)	5.60 (.24)	11.84 (.39)	15.82 (.68)	29.68 (1.27)
20.00	.42 (.02)	2.41 (.11)	5.11 (.20)	10.67 (.40)	14.42 (.61)	27.04 (1.19)
40.00	.36 (.02)	2.12 (.10)	4.50 (.21)	9.55 (.32)	12.98 (.53)	24.15 (1.17)
60.00	.30 (.02)	1.83 (.08)	3.94 (.19)	8.41 (.30)	11.40 (.50)	21.43 (.98)
80.00	-	-	-	7.21 (.28)	9.83 (.42)	18.32 (1.02)
100.00	-	-	-	6.02 (.26)	8.27 (.37)	15.74 (.68)
120.00	-	-	-	4.74 (.19)	6.62 (.33)	12.41 (.62)
140.00	-	-	-	3.62 (.15)	5.07 (.27)	9.66 (.54)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 6. Average Curve Factor

SOLAREX COMPENSATED BSF N/P 2 OHM-CM CG SILICON 2 X 2 X .005 CM TI-PD-AG CONTACTS TA205 A-R COATING NO COVERSLIDE SAMPLE SIZE 10						
CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	175.30	250.00
-160.00	.6492 (.0724)	.8028 (.0427)	-	-	-	-
-140.00	.6663 (.0791)	.8247 (.0342)	-	-	-	-
-120.00	.6902 (.0764)	.8360 (.0245)	.8574 (.0177)	-	-	-
-100.00	.7154 (.0691)	.8405 (.0244)	.8575 (.0109)	.8668 (.0090)	-	-
-80.00	.7380 (.0555)	.8387 (.0183)	.8555 (.0135)	.8540 (.0065)	.8523 (.0045)	-
-60.00	.7566 (.0428)	.8243 (.0273)	.8487 (.0094)	.8493 (.0062)	.8451 (.0069)	.8346 (.0086)
-40.00	.7560 (.0320)	.8164 (.0122)	.8378 (.0076)	.8359 (.0076)	.8296 (.0040)	.8185 (.0077)
-20.00	.7539 (.0269)	.8031 (.0100)	.8113 (.0088)	.8140 (.0062)	.8120 (.0065)	.8035 (.0102)
.00	.7417 (.0203)	.7943 (.0096)	.7928 (.0067)	.7938 (.0065)	.7953 (.0067)	.7946 (.0076)
20.00	.7265 (.0183)	.7685 (.0086)	.7783 (.0043)	.7741 (.0045)	.7752 (.0081)	.7630 (.0087)
40.00	.7037 (.0165)	.7434 (.0089)	.7517 (.0043)	.7508 (.0068)	.7547 (.0041)	.7365 (.0103)
60.00	.6735 (.0134)	.7169 (.0064)	.7278 (.0042)	.7281 (.0052)	.7270 (.0059)	.7101 (.0103)
80.00	-	-	-	.6944 (.0071)	.6962 (.0059)	.6690 (.0202)
100.00	-	-	-	.6591 (.0057)	.6617 (.0066)	.6406 (.0117)
120.00	-	-	-	.6052 (.0085)	.6114 (.0078)	.5804 (.0110)
140.00	-	-	-	.5551 (.0077)	.5621 (.0072)	.5356 (.0162)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

Table 7. Average AMO Efficiency

SOLAREX COMPENSATED BSF  
 N/P 2 OHM-CM CG SILICON  
 2 X 2 X .005 CM  
 TI-PD-AG CONTACTS  
 TA205 A-R COATING  
 NO COVERSLIDE  
 SAMPLE SIZE 10

CELL TEMP. (DEG. C)	SOLAR INTENSITY (MW/CM**2)					
	5.00	25.00	50.00	100.00	145.30	250.00
-160.00	12.50 (1.81)	16.69 (1.09)	-	-	-	-
-140.00	12.63 (1.77)	16.60 (.95)	-	-	-	-
-120.00	12.70 (1.55)	16.22 (.80)	16.72 (.63)	-	-	-
-100.00	12.54 (1.33)	15.52 (.79)	16.02 (.61)	16.69 (.57)	-	-
-80.00	12.47 (1.05)	14.84 (.69)	15.29 (.64)	15.77 (.56)	15.56 (.62)	-
-60.00	12.01 (.85)	13.80 (.69)	14.44 (.55)	14.99 (.51)	14.73 (.58)	14.82 (.62)
-40.00	11.24 (.69)	12.91 (.57)	13.52 (.52)	14.07 (.52)	13.72 (.53)	13.85 (.61)
-20.00	10.39 (.59)	11.83 (.54)	12.26 (.53)	12.91 (.43)	12.73 (.51)	12.88 (.57)
.00	9.40 (.49)	10.69 (.51)	11.21 (.47)	11.84 (.39)	11.69 (.50)	11.87 (.51)
20.00	8.33 (.42)	9.64 (.45)	10.23 (.40)	10.67 (.40)	10.65 (.45)	10.82 (.48)
40.00	7.10 (.40)	8.47 (.38)	9.01 (.42)	9.55 (.32)	9.59 (.39)	9.66 (.47)
60.00	6.01 (.32)	7.33 (.33)	7.88 (.37)	8.41 (.30)	8.43 (.37)	8.57 (.39)
80.00	-	-	-	7.21 (.28)	7.26 (.31)	7.33 (.41)
100.00	-	-	-	6.02 (.26)	6.11 (.27)	6.29 (.27)
120.00	-	-	-	4.74 (.19)	4.89 (.24)	4.97 (.25)
140.00	-	-	-	3.62 (.15)	3.75 (.20)	3.86 (.22)

NOTE: STANDARD DEVIATIONS ARE GIVEN IN PARENTHESES.

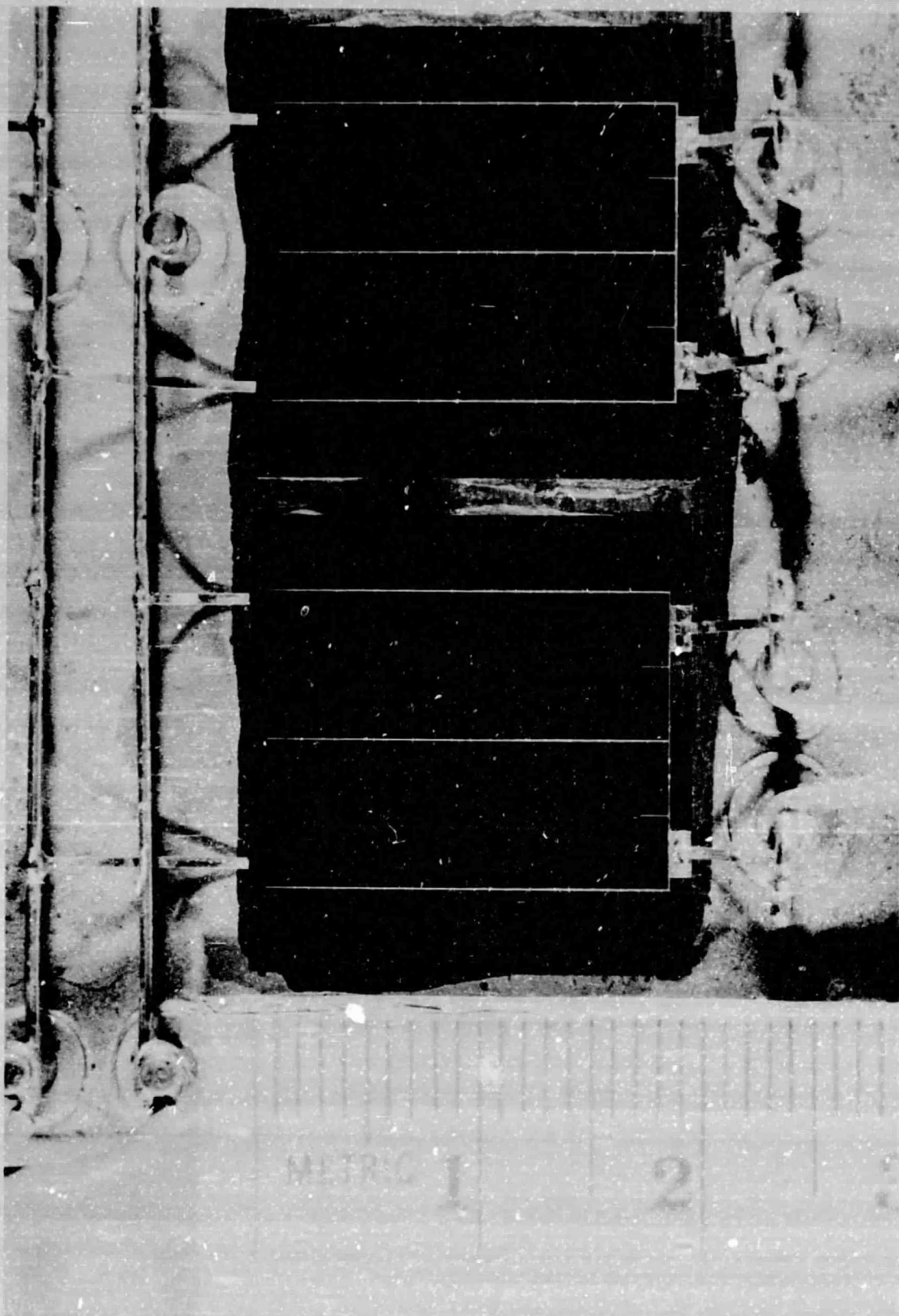


Figure A-1. Solar Cell

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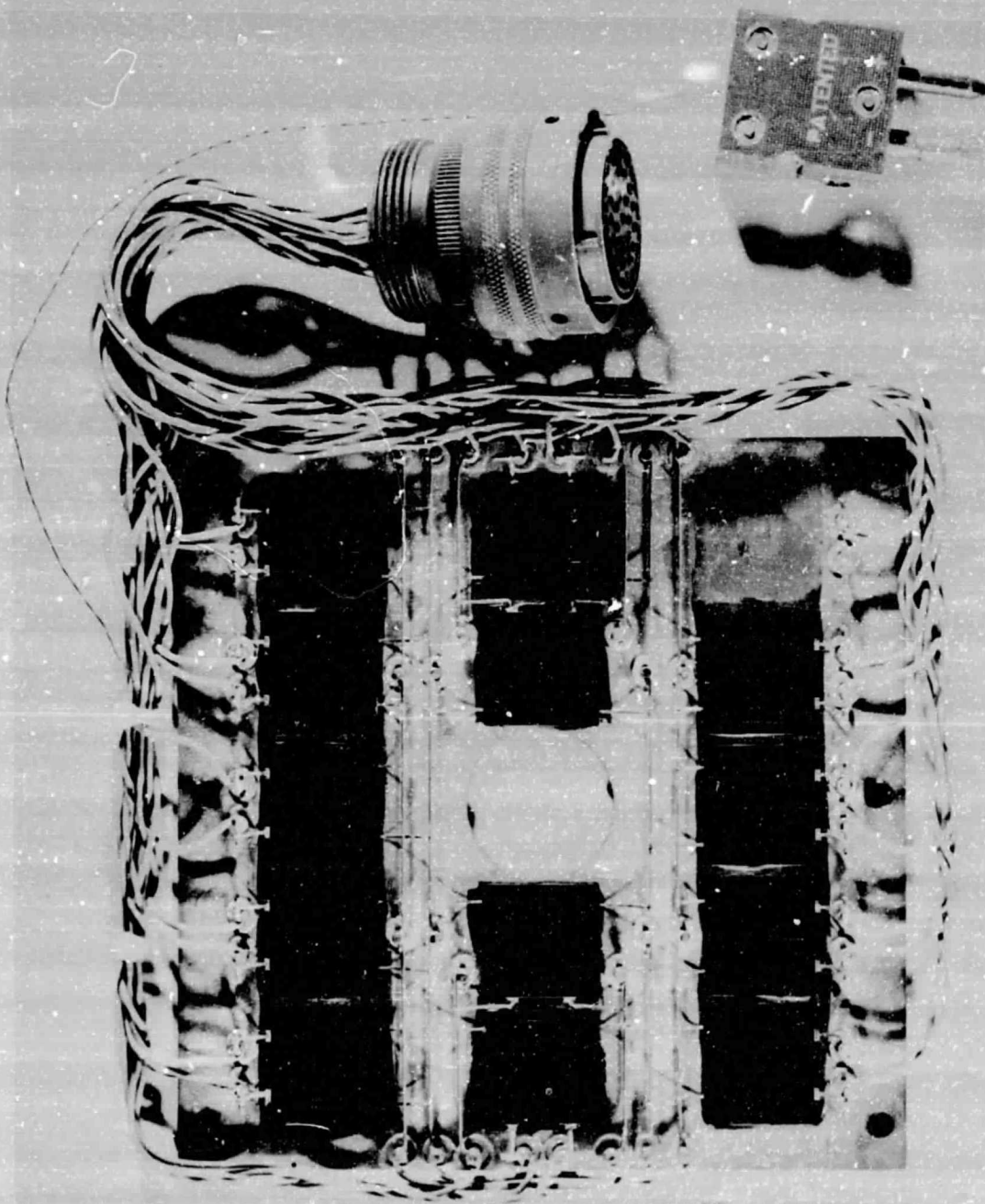


Figure A-2. Test Plate

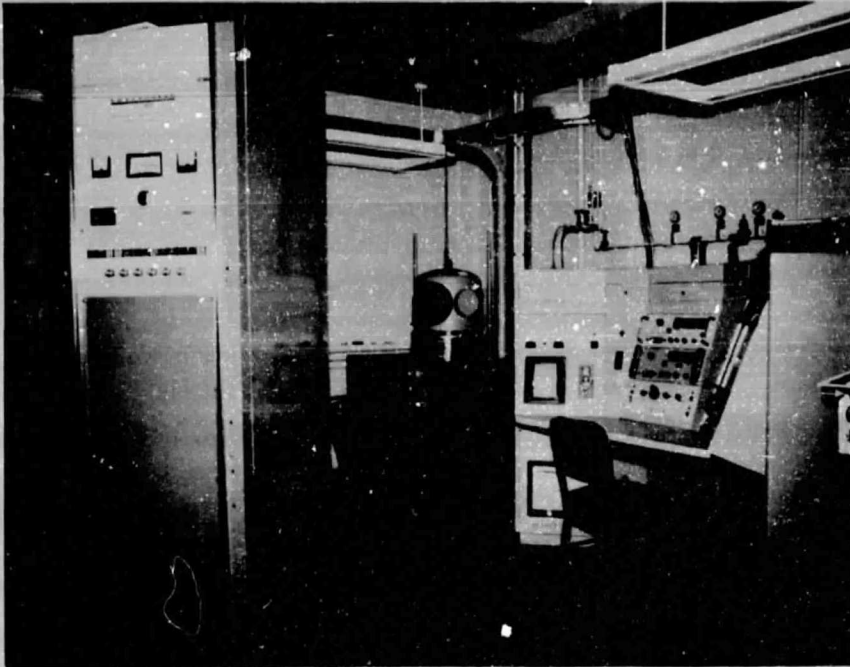


Figure A-3. Solar Cell Characterization Facility

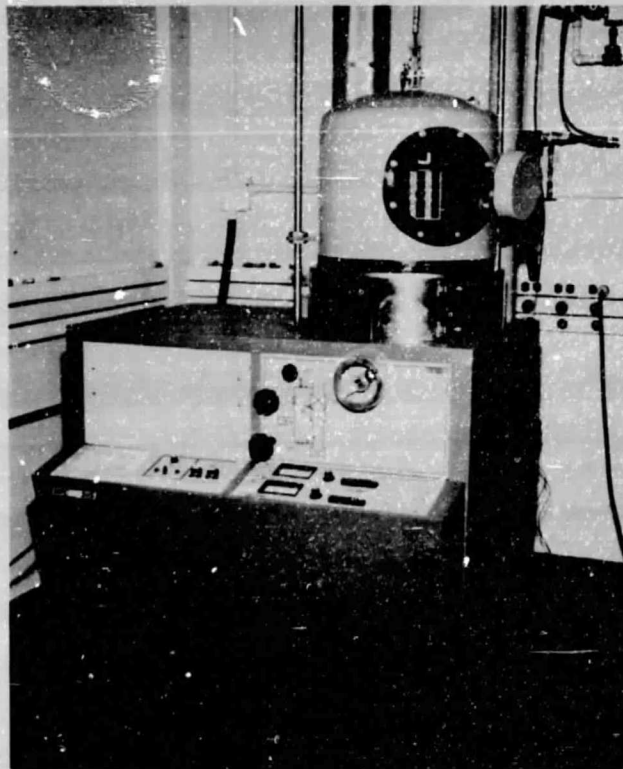


Figure A-4. Solar Cell Environmental Test Chamber